Radiation Safety Training Module: Diagnostic Radiology

Medical Imaging Techniques

Radiological Safety Division
Atomic Energy Regulatory Board

Contents

Objective

- To become familiar with basic knowledge of the components of the radiographic chain.
- To become familiar with the component of the fluoroscopy system (design, technical parameters that affect the fluoroscopic image quality and Quality Control).
- To understand the principles of interventional radiology system including equipment design, operational consideration and Quality Control.
- To understand the principles of dental radiology system and mammography system including design and Quality Control.
- To understand the principles and the technology of CT equipment.

Topics to know after studying this lecture

- Different modalities of X-ray imaging
- Different Detectors used in X-ray Imaging
- How X-ray image is formed in radiography?
- Difference between mammography system and diagnostic X-ray system
- Difference between Dental (intra-oral) and Dental (OPG) equipment
- Difference between radiography & CT images

Introduction

- X-rays were first discovered by German Physicist, W. C. Roentgen in 1895.
- In India, medical x-rays were first used in1898 within three years of the discovery of X-rays.
- In 1972, Computed Tomography was first introduced in medical field.
- In 1913, Albert Solomon, German Surgeon, was the first scientist who used X-ray techniques in breast cancer radiology which came to be known as mammography.
- In 1960, John R. Cameron invented the bone densitometer.

Introduction

- Medical imaging of the human body requires some form of energy (radiation). In imaging techniques used in radiology, the energy used to produce the image must be capable of penetrating tissues.
- In diagnostic X-ray imaging, images are formed by the interaction of the X-ray beam with the patient.
- As the X-ray beam passes through the patient, the photons interact with the body tissues and are absorbed/scattered by the patient. The degree of absorption is related to the density of the material that is in the beam's path.
- Dense objects (such as bone and metal) have a high degree of photon absorption, while less dense objects (such as fat and water) absorbs less photons.
- The differential absorption of photons by different materials in the photons' path results in the beam exiting the patient with different intensities. This is known as transmitted beam.
- A detector is used to measure the intensity variation, thus providing information on the different densities in the beam's path.

Imaging Modalities in Radiology

The different modes of making images are referred to as imaging modalities.

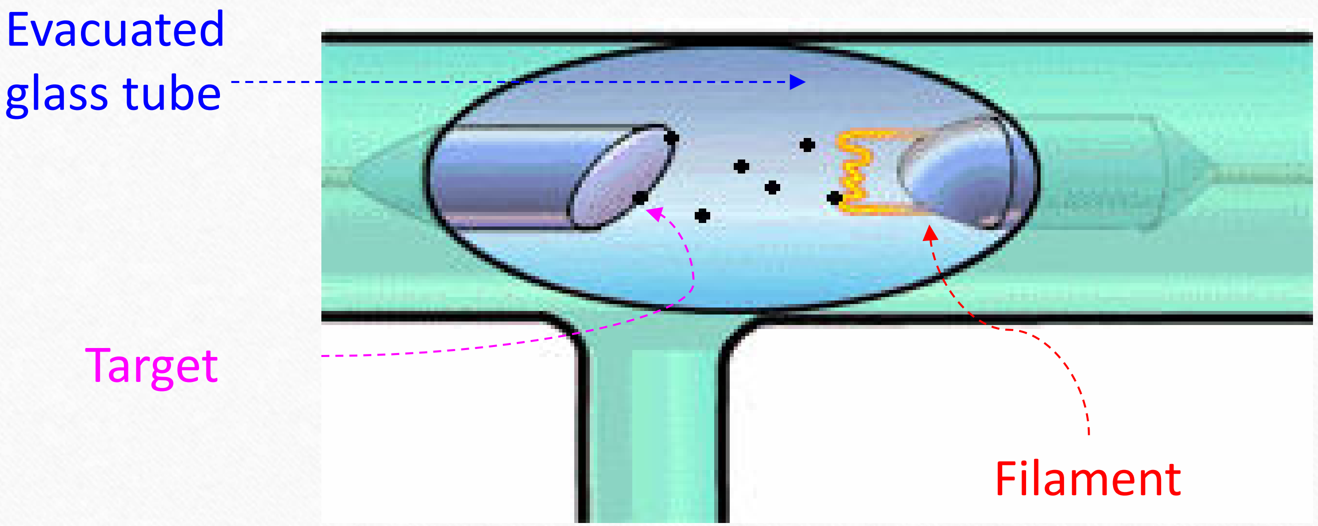
Each Imaging Modality has its own applications in medicine.

Various Modalities of Radiology are:

- Radiography
- Fluoroscopy
- Mammography
- Dental Radiography
- Bone Mineral Densitometry
- Computed Tomography

Origin of X-ray Source remains same for all x-ray imaging devices

i.e X-ray tube

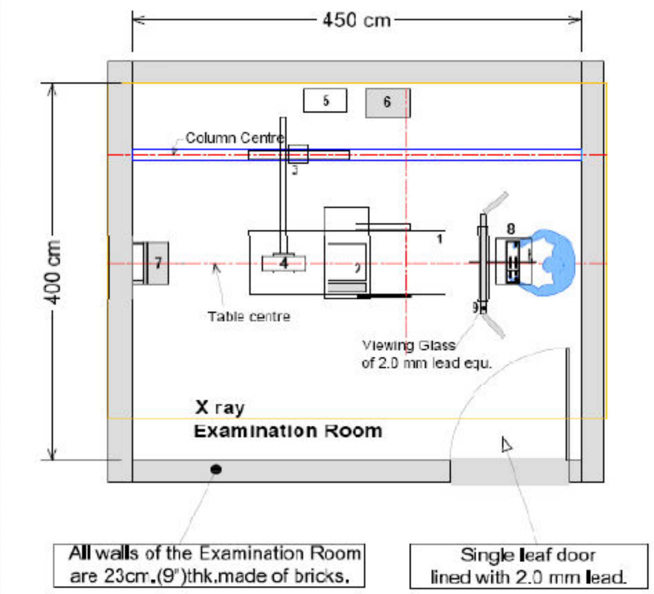


Radiography

- Radiography X-ray equipment has an x-ray tube on one side and an x-ray detector on the other side of the patient. A short duration pulse of x-rays is emitted by the x-ray tube, a large fraction of the x-rays interacts in the patient, some of the x-rays pass through the patient (transmitted x-rays) and reach the detector. These transmitted x-rays form the radiographic image on the film/detector.
- In radiography, the image is formed with screen-film system, CR cassette or with digital detectors.
- In screen-film radiography, areas of high intensity (thus low material absorption) within transmitted beam result in more blackening of the film, while areas of low intensity (thus high material absorption) will result in less blackening of the film. The film will remain white in areas with no photons.
- Human body is made up of tissues with varying densities, in the film black corresponds to tissues with little attenuation (such as air) and white corresponds to tissue with a high degree of attenuation (such as bone).

Radiography....

- Radiography is a transmission imaging modality.
- Radiography is also referred as projection imaging modality.
- Projection imaging refers to the acquisition of a two–dimensional image of the patient's three- dimensional anatomy.
- Typical tube voltages range from 50 -150 kVp.



Typical layout of a Radiography room

X-ray Image Formation

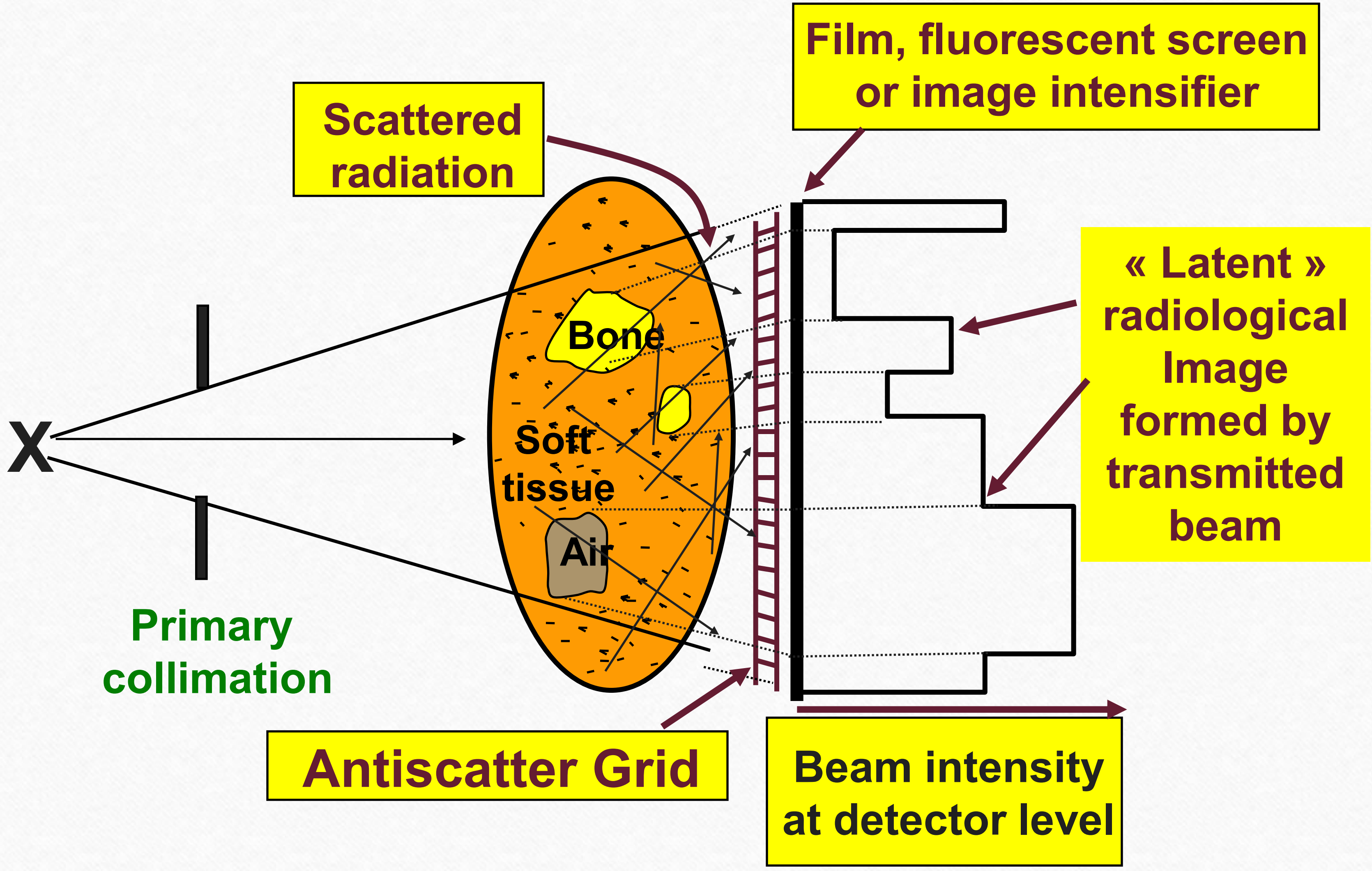


Image acquisition-Detectors used in Radiography

1) Screen film based
2) Photostimulable phosphor plates (PSP).
   - Called CR (computed radiography)

3)Direct digital radiography (flat panel detectors)

-------Direct conversion (selenium)

-------Indirect conversion (scintillation)

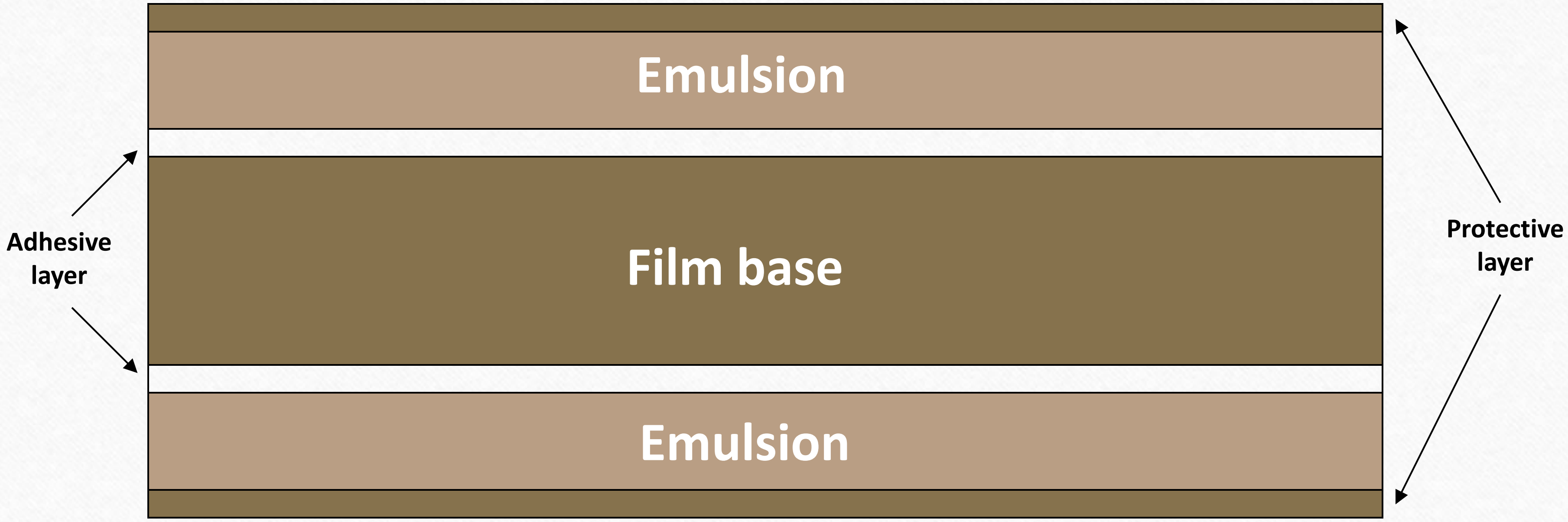
Detectors used in X-ray Imaging

Screen- Film System

- The X-ray film is sandwiched between two intensifying screens. Radiographic film consists of one or two layers of film emulsion {grains of silver halide, silver bromide (AgBr)and silver iodide (AgI) bounded in a gelatin base} coated on a flexible sheet of Mylar (a type of plastic).
- Intensifying screens are made of a scintillating material, called phosphor. Earlier screens use calcium tungstate phosphors, while now rare earth screens use gadolinium or lanthanum phosphors. Gadolinium Oxy Bromide and Lanthanum Oxy Sulphide are some commonly used intensifying screen phosphors.
- Intensifying Screens are used to reduce the radiation dose to the patient in diagnostic radiography.
- As X-ray films are more sensitive to light than X-rays, the Intensifying screen are used to convert X-rays falling on it into light. Each X-ray photon falling on the screen releases many light photons, which reach the film and form the image.
- Image formation is done by transmitted radiation. However, scatter radiation also reaches the film, thereby reducing the image quality. The antiscatter grid (bucky) is used to cut off the scatter radiation reaching the film. It is placed above the screen-film during imaging.

Film-Screen Imaging

Traditionally, all X-ray image capture has been through X-ray film



Intensifying screens

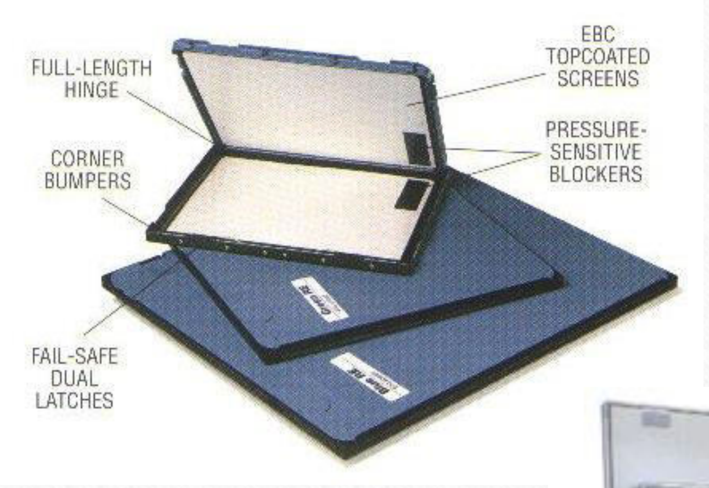
- Film is relatively insensitive to X-rays directly
  - Only about 2% of the X-rays would interact with the emulsion
  - Requires unacceptably high doses to give a diagnostic image
- An intensifying screen is a phosphor sheet the same size as the film, which converts the X-rays to a pattern of light photons
- The intensity of the light is proportional to the intensity of X-rays
- The pattern of light is then captured by the film
  - One exception is intraoral dental radiography, where screens are not practical

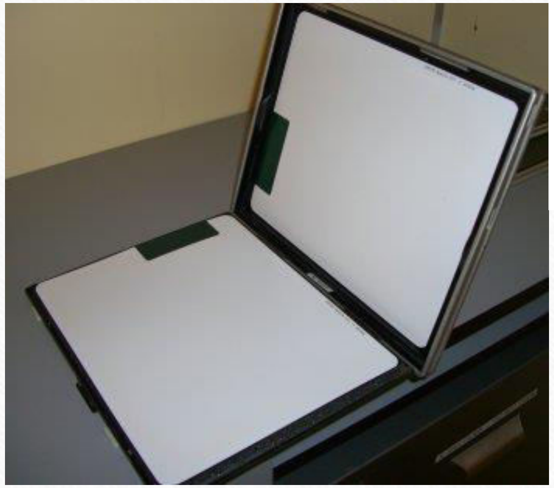
The film-cassette

- Flat, light tight box with pressure pads to ensure film in good contact with the screen(s) mounted on the front (and back)

- The tube side of the cassette is low atomic number material (Z~6) to minimise attenuation

- Rear of cassette often lead backed to minimise back scatter (not in mammography)





Film Processing

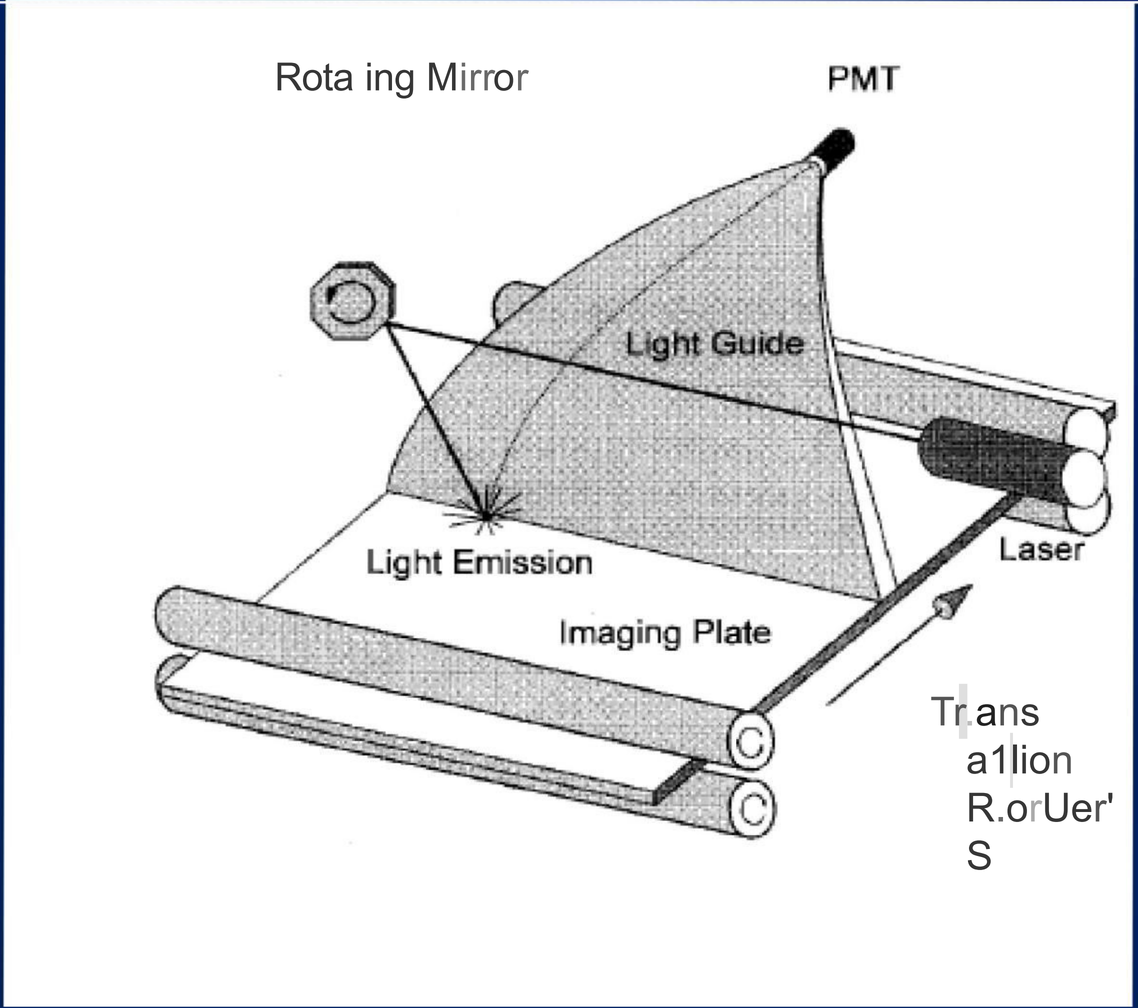
- The invisible latent image is made visible by processing
- There are three stages to this process;
  - Development
  - Fixing
  - Washing

Computed Radiography (CR)

Computed Radiography

- Computed radiography (CR) is a marketing term for photostimulable phosphor (PSP) detector systems.
- When X-rays are absorbed by photostimulable
- Phosphors, some light is promptly emitted much of absorbed energy is trapped in the PSP screen and can be read out later
- CR imaging plates are made of BaFBr and BaFI
- The imaging plate is exposed in a procedure identical to screen-film radiography and the CR cassette is then brought to a CR reader unit
- The cassette is moved into the reader unit and the imaging plate is mechanically removed

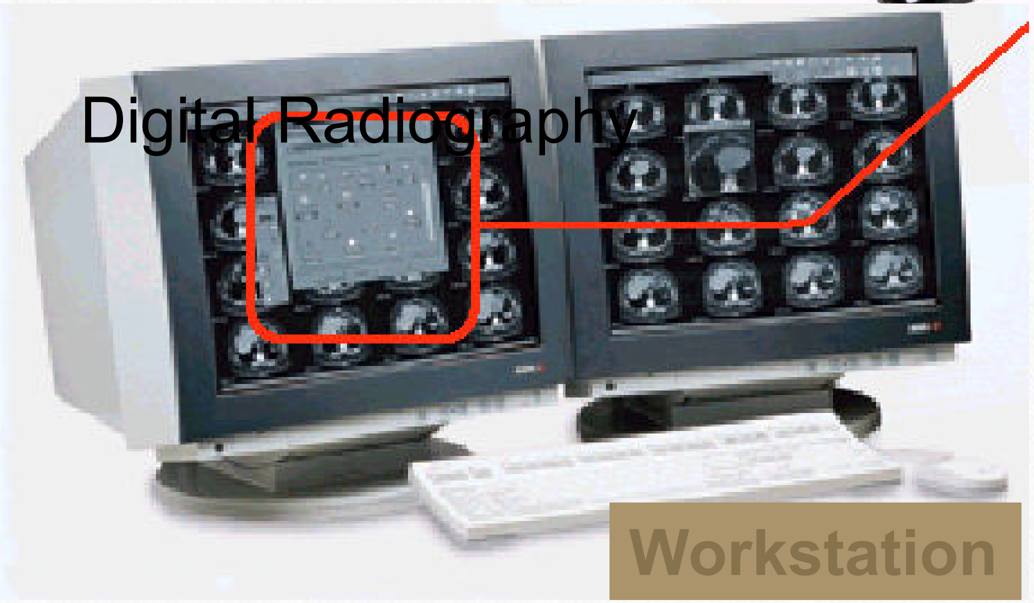
Illustration of C R Hardware



PSP digitizer

Cassette and PSP

Digital Radiography

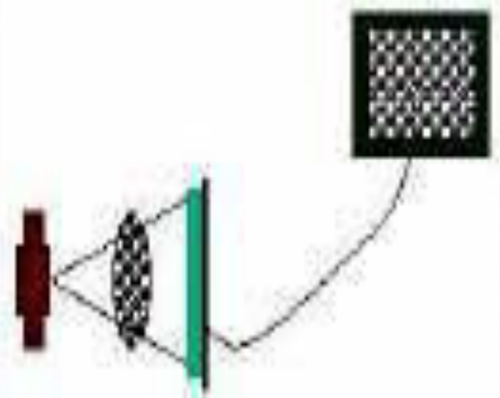


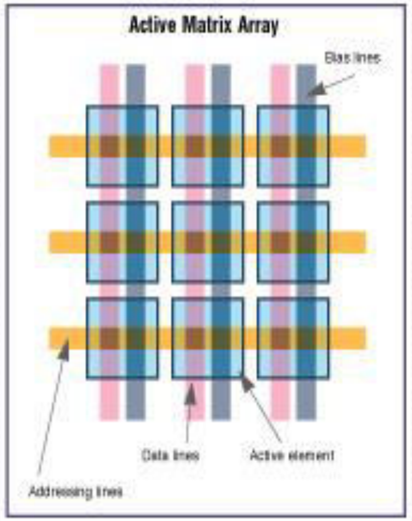
Workstation

Digital Radiography

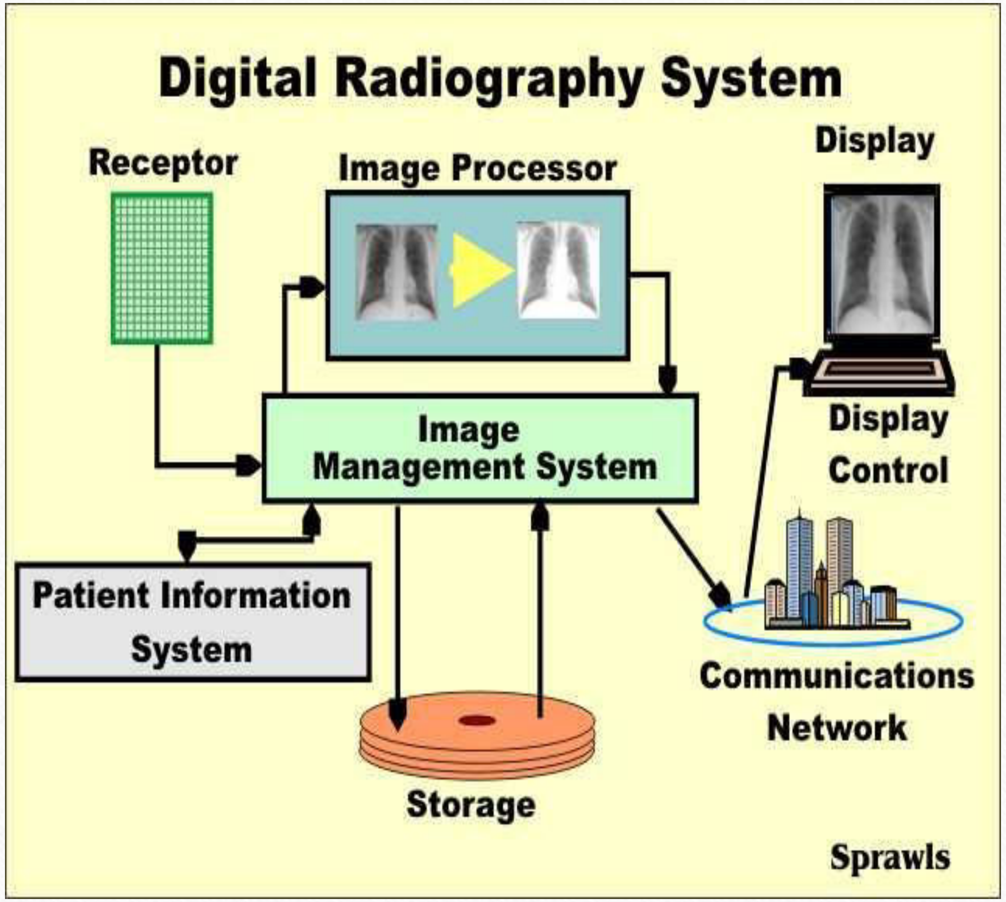
Digital Radiography (DR)

- Receptor provides direct digital output
- No processor / reader required
  - Images available in < 15 seconds
  - Much less work for technologist





Digital Radiography System



- Digital radiography is performed with a system of the following functional components:
  - A digital image receptor
  - A digital image processing unit
  - An image management system

Risk of increased doses

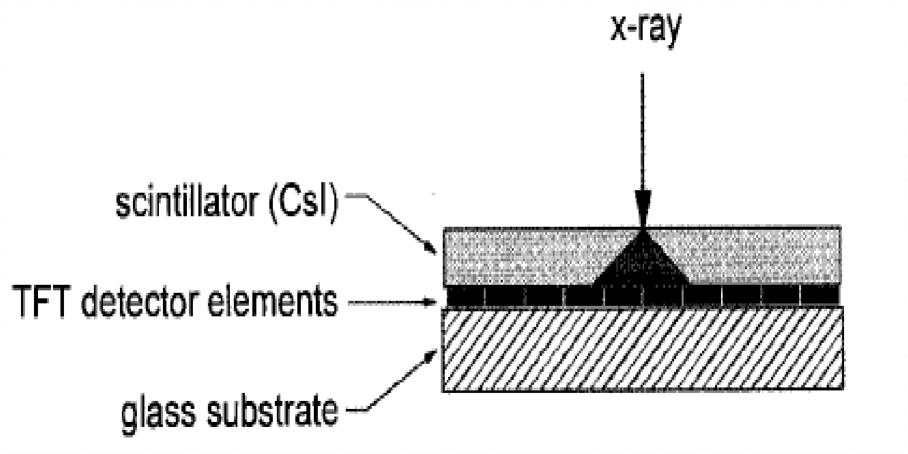
- The wide dynamic range of digital detectors results in good image quality while using high dose technique at the entrance of the detector and at the entrance of the patient
- This is not possible with conventional screen-film systems since high dose techniques always result in an image which is too dark

Detectors used in X-ray Imaging…

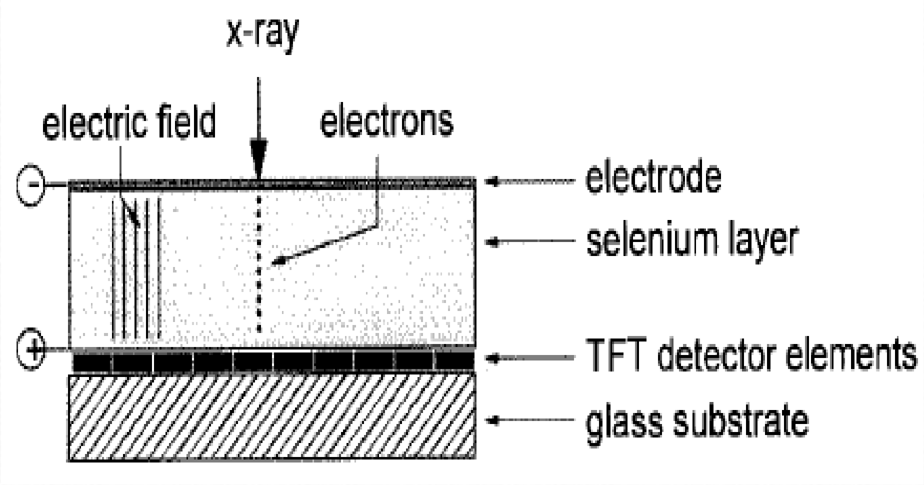
Flat Panel Detectors

Indirect Flat panel Detectors: Indirect flat panel detectors are sensitive to visible light, and an X-ray intensifying screen is used to convert incident X-rays to light, which is then detected by the flat panel detector. Silicon is commonly used flat panel detector.

Direct Flat panel Detectors: Direct flat panel detectors are made from a layer of photoconductor material on top of a Thin-Film-Transistor (TFT) array. Selenium is commonly used as the photoconductor.



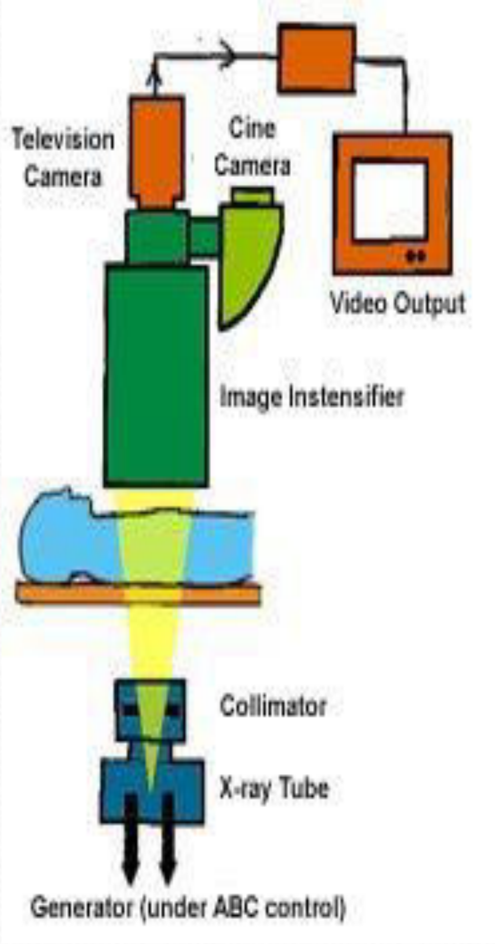
Indirect Flat Panel Detector



Direct Flat Panel Detector

Fluoroscopy

- Fluoroscopy refers to the continuous acquisition of a sequence of x-ray images over time, essentially a real-time x-ray movie of the patient. It is called dynamic imaging.
- Most general-purpose fluoroscopy systems use television technology, which provides images at the rate of 30 frames per second.
- Newer fluoroscopy systems allow the acquisition of a real-time digital sequence of images (digital video), that can be played back as a movie loop.
- Fluoroscopy is used for positioning catheters in arteries, for visualizing contrast agents in the gastrointestinal (GI) tract, and for other medical applications such as invasive therapeutic procedures where real-time image feedback is necessary.



Fluoroscopy….

Fluoroscopy mode of Operation

Continuous Fluoroscopy

- Continuous fluoroscopy is the basic form of fluoroscopy. It uses a continuously on x-ray beam using typically 0.5 and 4 mA (depending upon patient thicknesses).
- A video camera displays the image at 30 frames/sec, so that each fluoroscopic frame requires 33 milliseconds.

Pulsed Fluoroscopy

- In pulsed fluoroscopy, the x-ray generator produces a series of short x-ray pulses. Pulsed fluoroscopy offers better image quality in fluoroscopic procedures where body motion is high.
- Pulsed fluoroscopy at variable frame rates (typically 30,15 and 7.5 frames/sec) allows the fluoroscopist to reduce temporal resolution when it is not needed sparing dose in return.

Last –Frame –Hold

- When the fluoroscopist takes his or her foot off of the fluoroscopy pedal, rather than seeing a blank monitor, last-frame-hold enables the last live image to be shown continuously, until the next image acquisition.
- Last-frame-hold is very convenient and can reduce the dose to the patient.

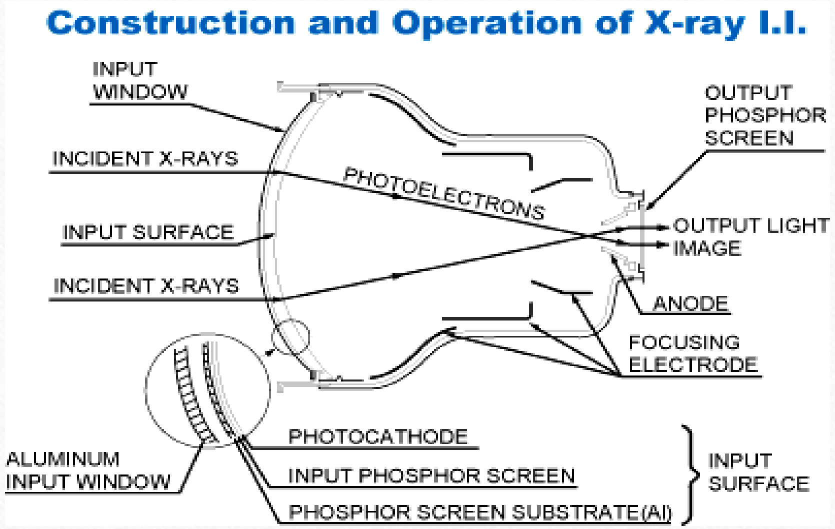
Detectors used in Fluoroscopy…

In fluoroscopy equipment following detectors are used:

- Intensifying Screen: Used in conventional fluoroscopy
- Image Intensifier: (discussed below)
- Digital detectors: As discussed in the earlier slides of Radiography

Image Intensifier

The function of the x-ray Image Intensifier is to convert an x-ray image into a minified light image.



Input screen (CsI): conversion of incident X-rays into light photons

1 X –ray photon creates ≈ 3,000 light photons

Photocathode: conversion of light photons into electrons

only 10 to 20% of light photons are converted into photoelectrons

Electrodes : focalization of electrons onto the output screen.

electrodes provide the electronic magnification

Output screen: conversion of accelerated electrons into light photons.

Fluoroscopy….

C-Arm equipment

- Ability to maneuver c-arm around patient without moving the patient
- Often used as “mobile” unit
  - Critical care units
  - Operation Theatre
- Modern units allow fluro + radiography

Fluoroscopy….

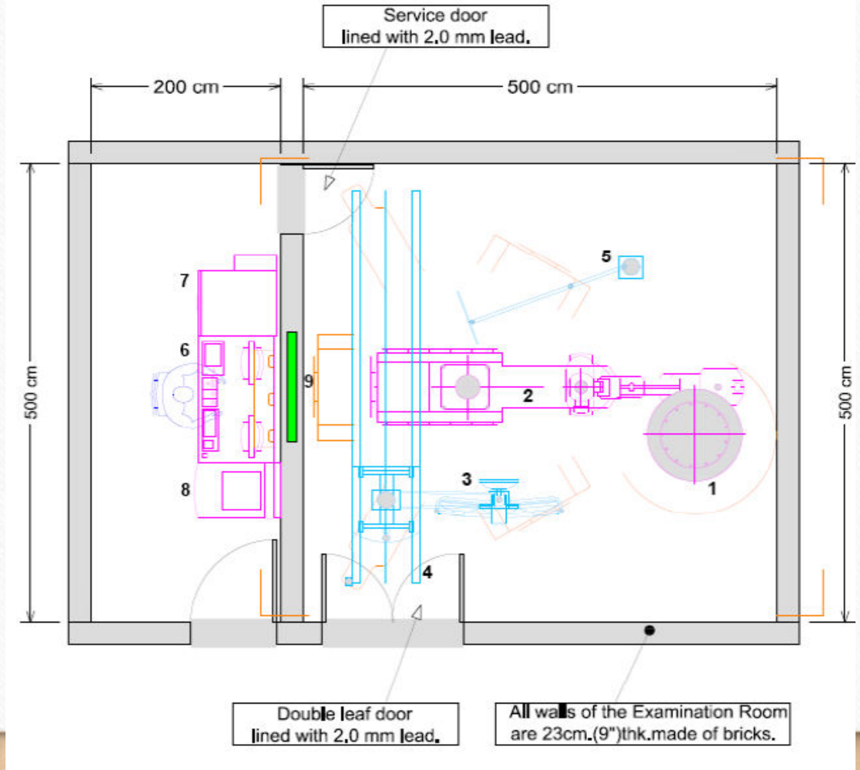
Angiography

- Angiography is a specialized fluoroscopic examination in which a contrast agent is used to highlight vasculature in the patient.
- Contrast is a radiographic (high density) material injected into the blood vessels of the patient.
- Vessels containing contrast show up dark on the image, while areas without contrast show up bright.
- Advanced techniques, such as Digital Subtraction Angiography can be utilized to improve vessel visualization and also guide percutaneous tools.

Fluoroscopy…..

Interventional radiology

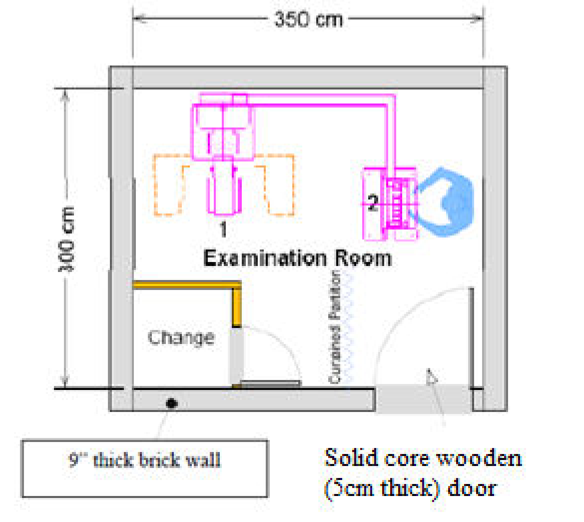
- Interventional radiology uses the high capacity C-arm equipment with additional features to guide minimally invasive surgical procedures.
- Interventional radiology comprises fluoroscopically guided therapeutic and diagnostic techniques.
- Interventional techniques are used during diagnostic interventions or for therapeutic purposes as well as during surgical procedures to guide or monitor the surgeon's actions.
- A good knowledge of equipment specification and characteristics is essential for an effective optimization of radiation protection



Typical layout of an IR facility

Mammography

- X-ray mammography is the most reliable method of detecting breast cancer.
- It is employed both as a screening tool and for diagnosis.
- Mammography also uses x-rays for breast imaging; however, there are fundamental differences between a mammography system and a diagnostic x-ray system. Due to the tissue characteristics of the breast and pathology of interest, mammography systems utilize lower tube potential (15-35 kVp).
- Molybdenum (Mo) and Rhodium (Rh) are the commonly used target/filter combinations in mammography. Characteristic X-ray produced by these target materials is used for breast imaging.
- In addition, two compression plates are used to decrease breast thickness and minimize motion, thus resulting in the less scatter radiation and better overall image quality.



Typical layout of Mammo room

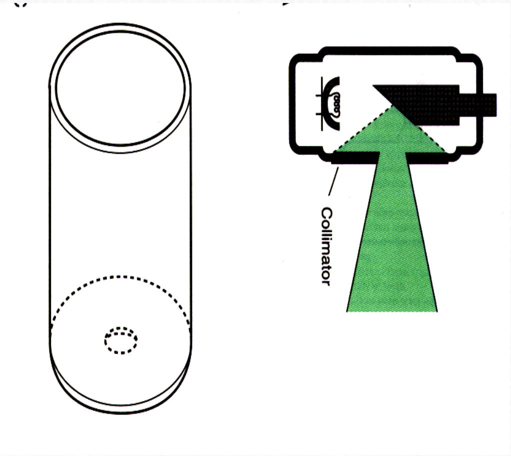
Dental Radiography

A) Dental (Intra-oral x-ray examination)

- Dedicated equipment used for radiography of tooth with low power stationary anode tube
- Tube is deployed on an extendable arm for easier positioning
- Tube potential : 60-70 kVp
- Tube current :   6-7 mA
- <u>Exposure is varied by altering the exposure time</u>
- Exposure time varies from 30 ms to 2.5 s
- Focus-skin distance   10 cm for 60 kV,

  20 cm for 60-75 kVp
- Diameter of lead cone (collimator) diameter shall be less than 7.5 cm at the end of cone.

It uses x-ray film (without film) or sensor for imaging purpose as detector.



Dental Radiography…

B) Dental (OPG)

- Both film and Tube head rotate around the patient:

  The X-ray tube rotates around the patient head in one direction and the film rotates in the opposite direction, while the patient sits (or stands) in a stationary position.

- The collimator used in the panoramic x-ray machine is a lead plate with a narrow vertical slit.
- The Tube head always rotates behind the patient head as the film rotates in front of the patient.
- Tube potential   85-90 kV
- Tube current: 4-15 mA
- Exposure time :   12 s (typically standard OPG scan)

  0.16-3.2 s (cephalometric projection)

- Flat panoramic cassette   15 cm x 30cm

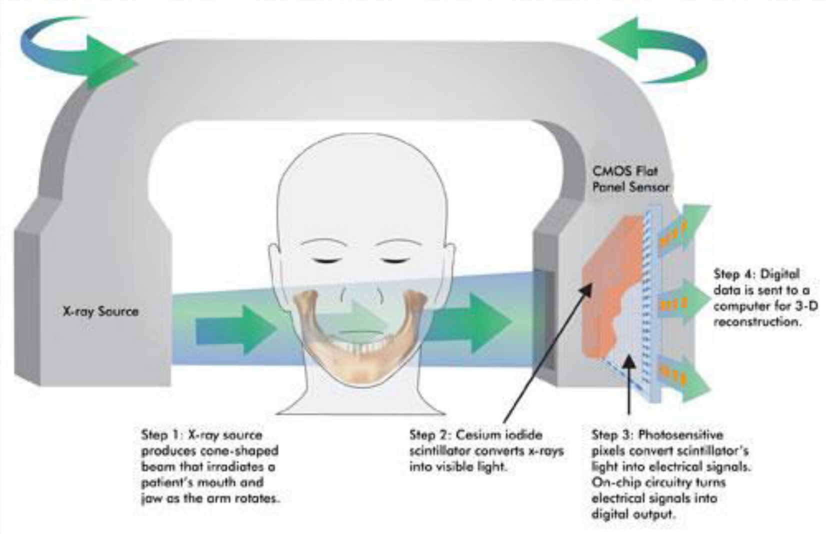
Dental Radiography…

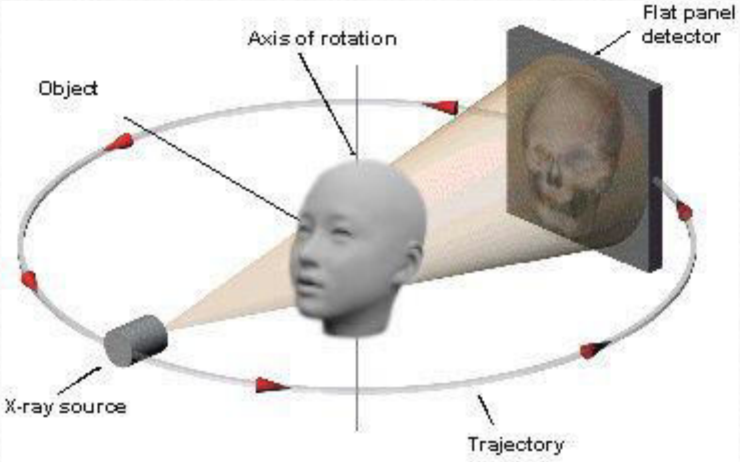
C) Dental (CBCT)

- Dental Cone Beam CT scanner uses a cone shaped x-ray beam rather than a conventional linear fan beam, as in the case of common CT, to provide images of the skull bony structures.

- Tube potential: 85-90 kV
- Tube current: 4-15 mA

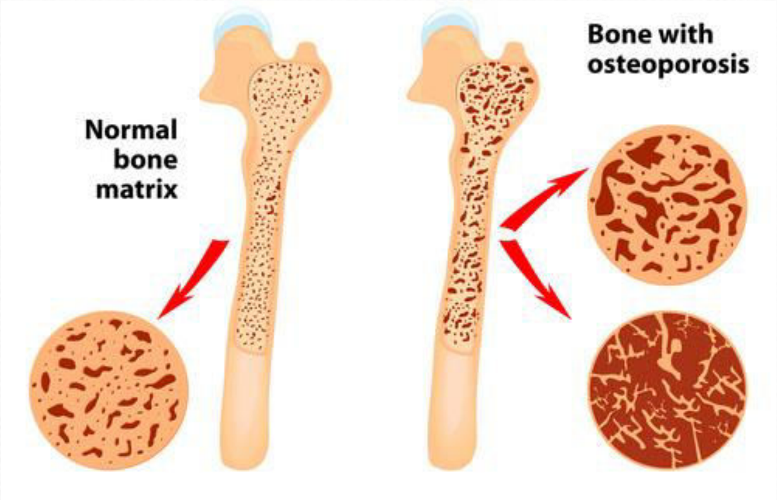
- Leakage from tube housing: less than 1.0 mGy in one hour at 1m from focus of Dental Cone Beam CT scanner.





Bone Mineral Densitometry Equipment

- Bone density or bone mineral density (**BMD**) is the amount of bone mineral in bone tissue.
- Bone density scanning, also called **dual-energy x-ray absorptiometry** (**DEXA**) or bone densitometry.
- Two x-ray beams with different energies are aimed at the patient's bones. When soft tissue absorption is subtracted out, the BMD can be determined.
- Tube potential : 80-140 kV
- Tube current : 1.5-7 mA
- Bone density testing is used to assess the strength of the bones and the probability of **fracture** in persons at risk for **osteoporosis**.



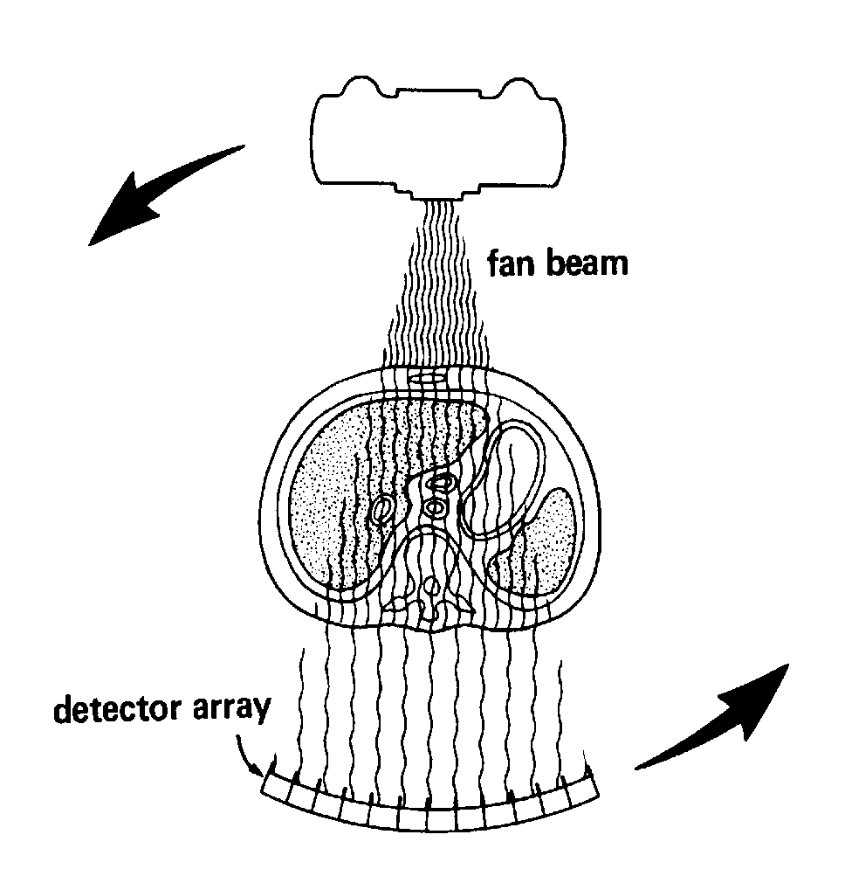
Computed Tomography

- Computed Tomography (CT) was introduced into clinical practice in 1972 and revolutionized X-ray imaging by providing high quality images which reproduced transverse cross sections of the body.

- The technique offered in particular improved low contrast resolution for better visualization of soft tissue, but with relatively high absorbed radiation dose.

- CT uses a rotating X-ray tube, with the beam in the form of a thin slice (about 0.5 - 10 mm).

- The “image” is a simple array of X-ray intensity, and many hundreds of these are used to make the CT image, which is a “slice” through the patient.

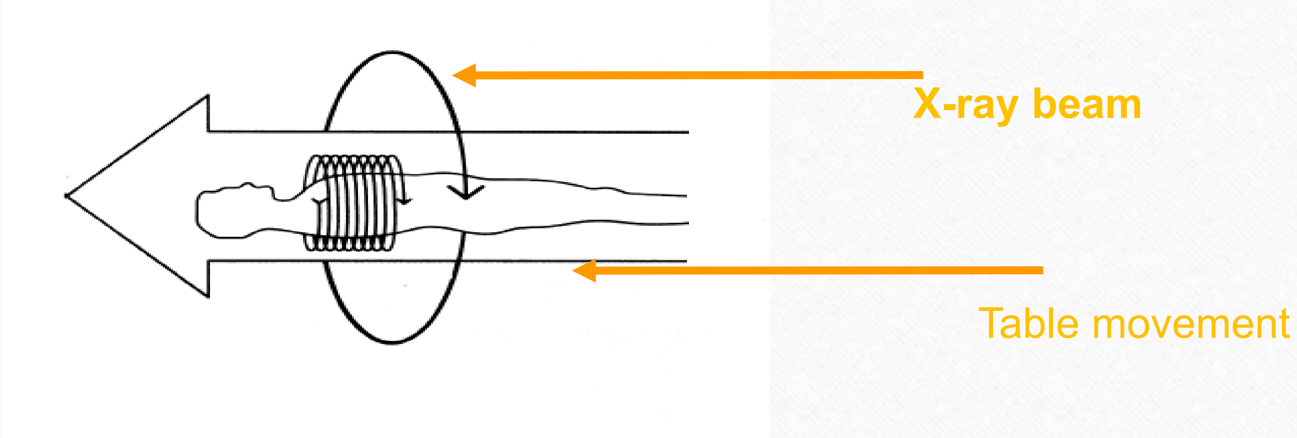


Computed Tomography

Helical Spiral (CT)

- If the X –ray tube can rotate constantly, the patient can then be moved continuously through the beam, making the examination much faster.
- For helical scanners to work, the X –ray tube must rotate continuously.
- Helical CT imaging allows for the continuous movement of the CT Couch during imaging.

- Scanning Geometry



- Continuous Data Acquisition and Table Feed

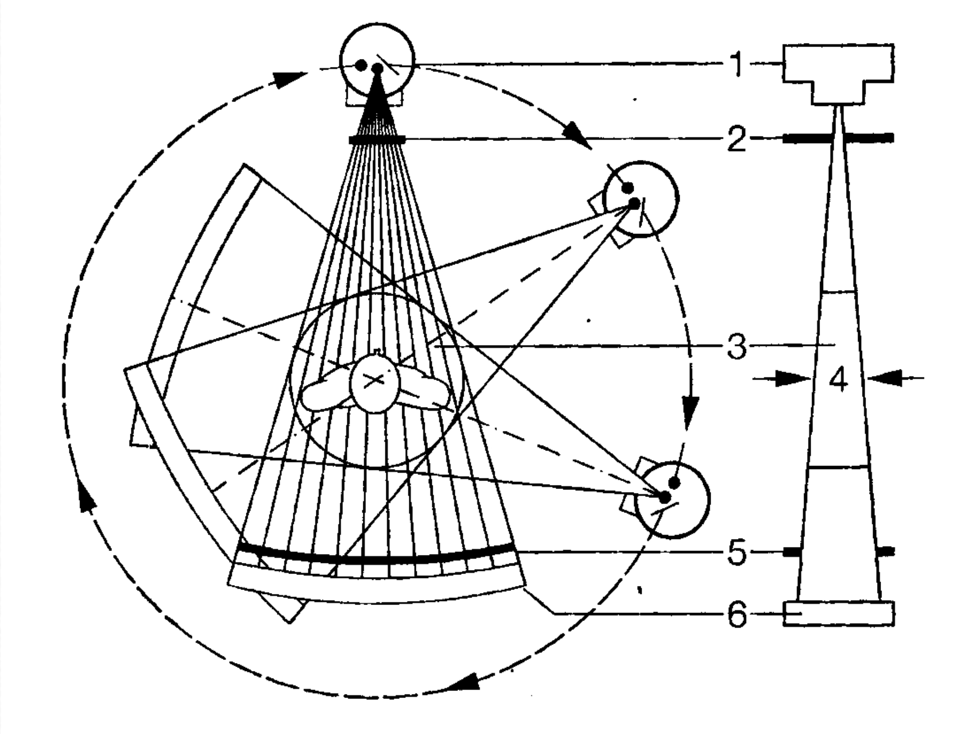
Computed Tomography

Generator

- High frequency, 30 - 70 kW

X- ray tube

- Rotating anode, high thermal capacity: 3-7 MHU
- Dual focal spot sizes: about 0.8 and 1.4 mm

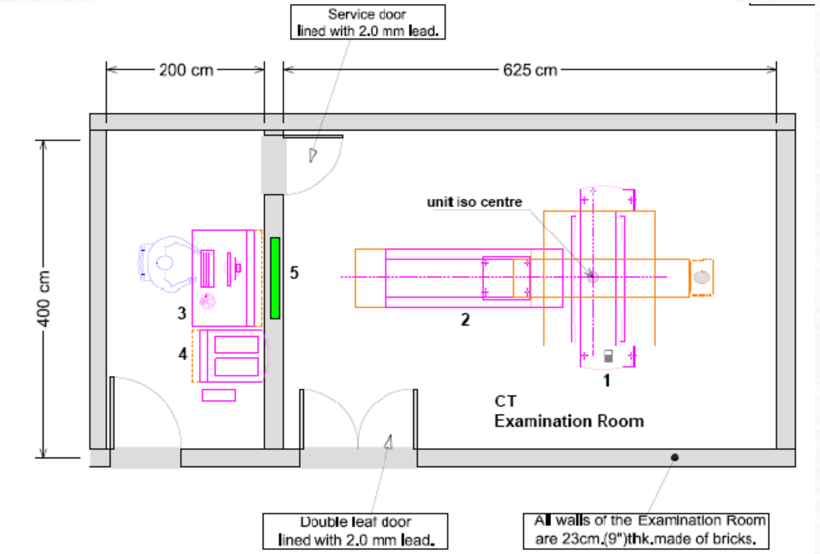


Gantry

- Aperture: > 70 cm of diameter
- Detectors: solid state; > 600 detectors
- Scanning time: <1 s, 1 - 4 s
- Slice thickness: 0.5 - 10 mm
- Spiral scanning: up to 1400 mm

Computed Tomography

- Computed Tomography (CT) images are produced by passing x-rays through the body, at a large number of angles, by rotating the x-ray tube around the body.
- Multiple linear array detectors, opposite the x-ray source, collect the transmission projection data. The numerous data points collected in this manner are synthesized by a computer into a tomographic image of the patient.
- The term tomography refers to a picture (graph) of a slice (tomo).
- CT is transmission technique that results in images of individual slices of tissue in the patient.
- The advantage of a tomographic image over projection image is its ability to display the anatomy in a slice of tissue in the absence of over or underlying structures .



Typical layout of CT room

Typical Technical Parameters of Diagnostic X-ray Equipment

Sr. No.	Type of diagnostic x-ray equipment	Maximum operating potential (kVp)	Maximum operating current (mA)
1	Radiography/Radiography & fluoroscopy	150	1100
2	C-Arm	110-120	150
3	Dental (intra-oral)	60-70	6-7 (up to 10 mA)
4	Dental (extra-oral) [OPG/CBCT]	85-90	10-15
5	Computed Tomography	140	800
6	Interventional Radiology	150	1250
7	Mammography	49 (Mainly 35 kVp)	200
8	Bone Densitometer	140	5-7

Summary/Learning Outcomes

- This Presentation gives a brief overview of all diagnostic x-ray imaging modalities.
- This presentation elaborates the technical aspects of various X-ray imaging modalities, image detection systems, operating parameters and image properties of medical diagnostic X-ray equipment.
- This presentation will be helpful for the medical professionals associated with use of diagnostic X-ray equipment for understanding the various x-ray based imaging modalities and their applications in the field of medicine.

Expected Questions

Q.1 How radiography examination is performed of a patient?

Ans. Radiography is performed with an x-ray source on one side and an x-ray detector on the other side of the patient. A short duration pulse of x-rays is emitted by the x-ray tube, a large fraction of the x-rays interacts in the patient, some of the x-rays pass through the patient (transmitted x-rays) and reach the detector. These transmitted x-rays form the radiographic image on the film/detector.

Q.2 Why intensifying screens are used in radiographic examinations?

Ans. Intensifying Screens are used to reduce the radiation dose to the patient in diagnostic radiography.

The main function of the Intensifying screen is to convert x-rays falling on it into light.

Q.3 What is the function of image intensifier?

Ans. The function of the x-ray Image Intensifier is to convert an x- ray image into a minified light image.

Expected Questions

Q.4 What is fluoroscopy?

Ans. Fluoroscopy refers to the continuous acquisition of a sequence of x-ray images over time, essentially a real-time x-ray movie of the patient. It is called dynamic imaging.

Q.5 How occupational exposure can be minimized in interventional radiological procedures?

Ans. Using protective lead aprons
Avoiding direct beam
Maintaining distance
Limiting the total beam–on time
Avoiding oblique lateral projections

Q.6 Which type of x-ray radiation is used in mammography examinations?

Ans. Characteristic x-ray radiation is used in mammography examinations.

Q.7 What is the limit of tube housing leakage for dental (intra oral) x-ray equipment?

Ans. Leakage from tube housing shall be leas than 0.25 mGy in one hour at 1m from focus of dental (intra-oral) equipment.

Expected Questions

Q.8 How Dental (OPG) scans of patient is performed?

Ans. In Dental (OPG) scans, the X-ray tube rotates around the patient head in one direction and the film rotates in the opposite direction, while the patient sits (or stands) in a stationary position.

Q.9 What is the advantage of tomographic image over projection image?

Ans. The advantage of a tomographic image over projection image is its ability to display the anatomy in a slab (slice) of tissue in the absence of over or underlying structures. It improves its image contrast

Q.10 What do you mean about the contrast of the image?

Ans. Contrast in an image is the difference in the gray scale of the image. It is the difference in darkness of the image and its surroundings.

References and sources for additional information

- The Essential Physics of Medical Imaging (J. T. Bushberg, J.A. Seibert, E.M. Leidholdt, J M Boone)
- The Physics of Radiology (H.E. Johns, J.R. Cunnighnam)
- IAEA Presentations on Diagnostic Radiology

List of presentations in the training Module

Basics of Diagnostic X-ray Equipment
Biological effects of Radiations
Medical X-ray imaging techniques
Planning of Diagnostic X-ray facilities
Quality Assurance of X-ray equipment
Quality Assurance of Computed Tomography equipment
Radiation Protection in Diagnostic Radiology Practice
Causes, prevention and investigation of excessive exposures in diagnostic radiology
Regulatory Requirements for Diagnostic Radiology Practice

THANK YOU